1. **Project Name:** **Novel Carbon Films for Next Generation Rotating Equipment Applications**

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5. **Date Project Initiated and FY of Effort:** April 1, 2002, 2nd fiscal year.

6. **Expected Completion Date:** December 31, 2003

7. **Project Technical Milestones and Schedule:**

• CDC Formation on SiC	Completed	12/31/02
• NFC Formation on SiC	Completed	12/31/02
• Testing of CDC in pin-on-disk	Completed	12/31/02
• Testing of CDC/NFC couples	In progress	
• Post-test characterization	In progress	
• Optimization of Coating couples	In progress	
• Supply of seals to industrial partner	Planned, Summer, 2003	
• Characterization of seals after industrial service	Planned, Fall, 2003	

8. **Past Project Milestones and Accomplishments:**

The aim of this proposal is to combine two complementary carbon technologies, Near Frictionless Carbon (NFC) and Carbide Derived Carbon (CDC), to achieve the longest wear life, the highest reliability and the greatest energy savings in mechanical pumps and other rotating machinery applications. NFC is a diamond like carbon containing a high hydrogen content, which is applied by a plasma deposition process. CDC is a conversion coating, which can be produced on SiC at a low cost by an atmospheric pressure chlorination treatment. NFC is capable of producing very low friction coefficients, while CDC produces low friction coefficients and excellent resistance to spallation and delamination, important failure modes for tribological coatings.

We have demonstrated that these two carbon materials can be combined in a single tribological couple, which can combine the excellent properties of both coatings. In addition, by applying some of the process approaches in NFC preparation in the CDC synthesis process, we have been able to improve the tribological performance of the CDC coating. This research is ongoing to develop a combined coating with optimal properties of low friction, wear resistance and resistance to spallation.

9. **Planned Future Milestones:**

Optimal carbon coatings will be prepared and applied to SiC seal rings. These will then be supplied to our industrial partner for testing in simulated and real service environments. Subsequently, the parts will be collected after testing and characterized to evaluate the performance.

10. **Issues/Barriers:**

Currently, the work is going very well and we have not encountered any technical barriers, which would be likely to prevent the achievement of the goals of the program. Instead, the research has led to the identification of new processing options which may permit us to produce better tribological systems at lower cost than was anticipated at the beginning of the program. In particular hydrogen treatment of the CDC has produced demonstrable improvements in performance. Investigation of the mechanism of this effect and optimization of the process parameters for these treatments will provide opportunities for production of even better coatings than were considered in the initial proposal.

11. **Intended Market and Commercialization Plans/Progress:**

The intended end-use application is in mechanical pump seals. Mechanical shaft seals used in pumps are critical to the operation of the paper, pulp, and chemical process industry, as well as the petroleum and nuclear power generating plants to prevent the leakage of gases and hazardous chemicals from rotating equipment. We are currently addressing intellectual property issues to transfer this technology to commercial entities that can implement the coatings in commercial products on an industrial scale. We have identified potential users with needs for more durable pumps in sensitive applications where some additional initial costs to produce coated seal faces would be offset by reduced maintenance costs in service. Negotiations are in process to implement this activity.

12. **Patents, publications, presentations:** (Please list number and reference, if applicable.)

TRIBOLOGICAL CHARACTERIZATION OF CARBIDE-DERIVED CARBON (CDC) FILMS IN DRY AND HUMID ENVIRONMENTS, B. CARROLL, Y. GOGOTSI, A. KOVALCHENKO, A. ERDEMIR, M.J. McNALLAN**,** *Nanostructured Materials and Coatings for Biomedical and Sensor Applications*, Y. Gogotsi, I. Uvarovna, Eds., Kluwer Scientific Publishers, in press.

Tribological Properties of Nanostructured Carbide-Derived Carbon (CDC) Films, by Y. Gogotsi, B. Carroll, A. Kovalchenko, A. Erdemir, M.J. McNallan, presented at the 39th Annual Technical Meeting of the Society of Engineering Science, October 14-16, 2002 at Penn State University.

Characterization and Tribological Testing of Carbide-Derived Carbon Films on SiC Substrates, by Beth Carroll, Yury Gogotsi, Michael McNallan, Ali Erdemir, Andriy Kovalchenko, presented at the 2002 MRS Fall Meeting in Boston, MA, December 2, 2002

Structure and Composition Optimization of Carbide-Derived Carbon Films for Tribological Applications, A. Kovalchenko; Argonne National Laboratory, Y. Gogotsi; Drexel University, A. Erdemir; Argonne National Laboratory, M. McNallan; University of Illinois at Chicago, B. Carroll; Drexel University, presented at the International Conference
on Metallurgical Coatings and Thin Films , San Diego, CA, May 1, 2003.

Effect of Annealing and Environment on the Tribological Behavior of Carbide-Derived Carbon Films, Beth Carroll, Yury Gogotsi, Drexel University, Michael McNallan, University of Illinois at Chicago, Ali Erdemir, Andriy Kovalchenko, Argonne National Laboratory, presented at the Society of Tribologists and Lubrication Engineers 2003 Annual Meeting, New York City, May 1, 2003.

The following paper has been accepted for publication in a reviewed journal:

EFFECT OF HUMIDITY ON THE TRIBOLOGICAL PROPERTIES OF CARBIDE-DERIVED CARBON (CDC) FILMS ON SILICON CARBIDE, B. Carroll and Y. Gogotsi*, Department of Materials Engineering, Drexel University, A. Kovalchenko and A. Erdemir**,** Energy Technology Division, Argonne National Laboratory, M.J. McNallan, Department of Civil and Materials Engineering, University of Illinois at Chicago, accepted for publication in **Tribology Letters**, February 2003.

Highlight

The CDC treatment coating has been submitted to Research and Development Magazine as an entry to the RandD 100 contest this year. Note that the NFC film won this award in 1998. We have high expectations for the nomination because of the excellent performance of the CDC coating in tribological testing to date.